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Growth and yield respones of maize (*Zea mays* L.) to soil water deficits.
II. Effects of water deficit timing and strength[1]

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Abstract : Water is a major limiting factor on maize production in Taiwan. It is very important, therefore, to study the relations of soil moisture stress and maize (*Zea mays* L.) yield under local conditions. This field work was conducted on the experimental farm of Taiwan Agricultural Research Insitiute (TARI) at Wufeng, Taiwan to evaluate the relative effects of water deficit timing and strength on the growth and yield of maize, cultivar Tainung No. 1. Water stress was imposed by the withholding of irrigation during reproductive growth phase (fall crop 1991) and vegtative growth phase (spring crop 1992), respectively, to cause soil water potentials to the range from − ⅓ (control) to − 10 bars. It was shown that leaf number per plant was not significantly affected by water stress in both seasons, whereas leaf area per plant was reduced when soil water potential lowered to −5 bars in the fall crop of 1991 and −8 bars in the spring crop of 1992. As indicated by plant height measured at the 50% silking, a 13-day period of water deficit to − 8 bars in the vegetative growth phase of spring crop influenced plant growth in the long run. The heading and the silking dates were not dramatically changed by water deficits in both crops. But more than 10% reduction of plant weight was recorded as soil water potential decreased to below −5 bars in the reproductive phase. Ear weight and kernel yield were decreased by water stress below −2.5 bars in both crop seasons. Kernel yield was reduced to 60 and 80% of the control at −10 and −8 bars in fall crop and spring crop, respectively, which mainly associated with a lower kernel weight. It is suggested that soil water potential can be employed on predicting maize production by water deficit and kernel yield reduction depends on severity of soil water stress.

Key words : Growth, Maize, Soil water deficit, Strength, Timing, Yieid.

INTRODUCTION

Maize is ofter grown in areas of subtropical rainfall and limited irrigation in Taiwan. As energy costs and the demand of water by industry and home usage go up, timely irrigation before the occurrence of crop injury by water stress becomes an important issue for cultivated lands where water resources are limiting.

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Maize is known liable to moisture stress. An ample amount of information is available with regard to the effects of water deficit on maize water relations and the related metabolic processes and morphological variations (Acevedo *et al.*, 1971; Beadle *et al.*, 1973; Boyer, 1970a; Hsiao, 1973; Lawlor, 1978; McPherson and Boyer, 1988; Ouatter *et al.*, 1987a, 1987b; Turner and Begg, 1974; Westgate and Boyer, 1985). It is less clear, yet important, on quantitative relationship of water stress level and yield of maize and the effect of stress timing.

Maize has distinct phases of plant development (Johnson and Tanner, 1972; Ritchie *et al.*, 1986), however, there remains uncertainty about the developmental sensitivity to the adverse effects of water deficit, i. e., their sensitivity to water deficits and ultimate effects of water stress of kernel yield. Substantial yield losses have been reported when water deficits occur during vegetative growth (Denmead and Shaw, 1960; Lorens *et al.*, 1987; Miller and Duley, 1925). Classen and Shaw (1970) reported that from one week prior to silking to two weeks after silking is the greatest sensitive period of kernel yield to water stress. Grant *et al.* (1989) further indicated that kernel number is especially sensitive to moisture stress during the seven days period after silking, whereas kernel weight is reduced during the kernel filling period. Moss and Downey (1971) suggested that stress prior to silking causing the shortage of carbohydrate results in reduced kernel number. Such information is required for water management and cost reduction planning in maize production in local conditions.

Under the competitive field environment where dry conditions of varying duration and intensity may occur frequently during the growing season, a better picture of the quantitative relationship between corn yield and the level and timing of water deficit would be helpful in establishing of strategies for maize-irrigation management. Experiments were therefore made to study longer term effect of maize growth and yield subjected to a period of soil water deficit during vegetative or reproductive phase. The relative effects of water stress on the agronomic traits associated with yield reductions were also evaluated.

MATERIALS AND METHODS

Two separate experiments were conducted in the fall crop of 1991 and the spring crop of 1992, respectively, to study the effects of water deficit imposed at different growth phases on maize growth and yield. Maize cultivar 'Tainung No. 1' was sown 10 August 1991 on a silt loam (mixed, nonacid, hyperthermic, Fluvaquentic Dystrochrept) at the experimental farm of TARI. In 1992, the hybrid was planted on 28 February. The soil contained 22.4% clay, 51.1% silt and 26.5% sand with 1.77% (fall) and 2.23% (spring) organic matter and with pH 6.2 (fall) and 5.6 (spring) in the top 20 cm soil layer. The bulk densities were 1.25 and 1.55 g cm^{-3}, and the soil moisture contents were 27.72 and 28.23% at $-1/3$ bar and 9.25 and 7.79% at -15 bars in the fall and the spring, respectively. Seeds were hand-planted three per hill in 9.0 m north-south rows with 0.25 m in-row and 0.70 m between-row spacings and then thinned to one seedling per hill a week later resulting in a final population of 57,100 plants ha^{-1}. Each experimental plot consisted nine rows with outer two rows as borders.

Restricted by weather conditions, the hybrid was subjected to soil moisture deficits in either reproductive, fall crop 1991, or vegetative, spring crop 1992, phase by withholding irrigation water until the desired levels of water stress were reached. Three water potential ranges, i. e., -2.5, -5.0 and -10.0 bars, were made in fall; whereas -8.0 bars, instead of

−10.0 bars, was attained in spring. Soil water potential was maintained within field capacity (measured by tensiometer), which was based on measured water contents in the root zone profile at 0.20 m depth, in control plots. The gypsum blocks were buried, two for each plot, prior to stress treatments and a predetermined resistance and soil water potential relationship was used to calculate soil water potential in each plot between 1300 to 1400 every day during the treatment periods. In fall crop the stress period was 20 days in duration and imposed from 10 September, which corresponding to one week before tasseling, to 29 September, during early reproductive development. In spring corn plants were exposed to different soil moisture ranges at the time of the eighth to the tenth leaf on the main culm (25 April to 7 May) in vegetative growth phase. Enough water was added by furrow irrigation to the experimental plots when the soil water potential approached the desired value and the plots were irrigated as the optimal irrigation treatment (control) thereafter.

Fertility was maintained with a side-dress applications of commercially available fertilizers (50—70—50 kg ha^{-1}; N-P_2O-K_2O) onto the soil surface at planting. Additional 120 kg ha^{-1} of nitrogen (in the form of ammonium sulfate) was applied with equivalent at 3, 6 and 9 weeks after planting. On sowing, the insecticide carbofuran (2, 3-dihydro-2, 2-dimethyl-7-benzofuranyl methyl carbamate, 3% granule, 30 kg ha^{-1}) was applied on soil surface after planting and was again sprayed on the canopy using 40.64% fluid at a rate of 1.2 L ha^{-1} at 5 weeks after planting. Weed control was achieved with hand weeding applied on 4 weeks after planting. The meteorological data were collected from the weather station at TARI experimental farm.

Six plants of each treatments were sampled on 30 September 1991 and on 22 May 1992 to investigate changes of plant height, leaf number, and leaf to different soil moisture levels. Maize height was measured from the soil surface to the highest point of plant. Numers of leaves per plant were counted on leaves with more than 50% area were green. Leaf area was measured on a Li-Cor model LI-3,000 area meter (Li-Cor, Inc., Nebraska, USA). Dry weights of stem and leaf were measured after oven-dried at 80 °C for 72 h. Soil core samples were taken to a depth of 0.20 m and a diameter of 0.20 m from the base of the stem. Roots were collected by washing out soil from sample, oven-dried at 80 °C for 72 h and weighed. Two middle-rows of plants were hand-harvested on 21 October 1991 and 23 June 1992, respectively, to determine ear number, ear length, ear weight, and kernel weight. The latter two parameters were converted to the weight per hectare and yield was determined. The effective plant percentage (EPP) at harvest was calculated by counting the number of plants with ear(s) in each plot relative to the seedling numbers (after thinned to one seedling per hill).

The field layout was a randomized complete-block design (RCBD) with four replications. Analyses of variance and the LSD test were used to determine differences in maize growth parameters and yield between water deficit treatments. Linear regression analyses were performed to determine the relationships between kernel yield and growth parameters and soil water potential in two crop seasons.

RESULTS AND DISCUSSION

Maize hybrid cultivars are often developed in near optimal environment of water availability in Taiwan, still frequently are grown under various levels of soil moisture stress

in field. The study of the response of maize growth and yield to water deficits is therefore needed and valuable in planning irrigation schedule and management programs aimed at conserving water while attaining acceptable maize yield.

The daily mean temperature, irradiance and rainfall during the growing seasons of 1991 and 1992 were shown in Figures 1 and 2, respectively. A distinct climatic pattern was shown, which not only restricted the imposed stress duration and soil water potential (Fit. 3) but governed growth behavior of maize. The accumulated amount of temperature, irradiance and rainfall were 1,919.4 °C, 1,008.3 MJ m^{-2} and 257 mm for fall crop and 2,666.5 °C, 1,304.2 MJ m^{-2} and 660 mm for spring crop. The climate was wet in spring than in fall.

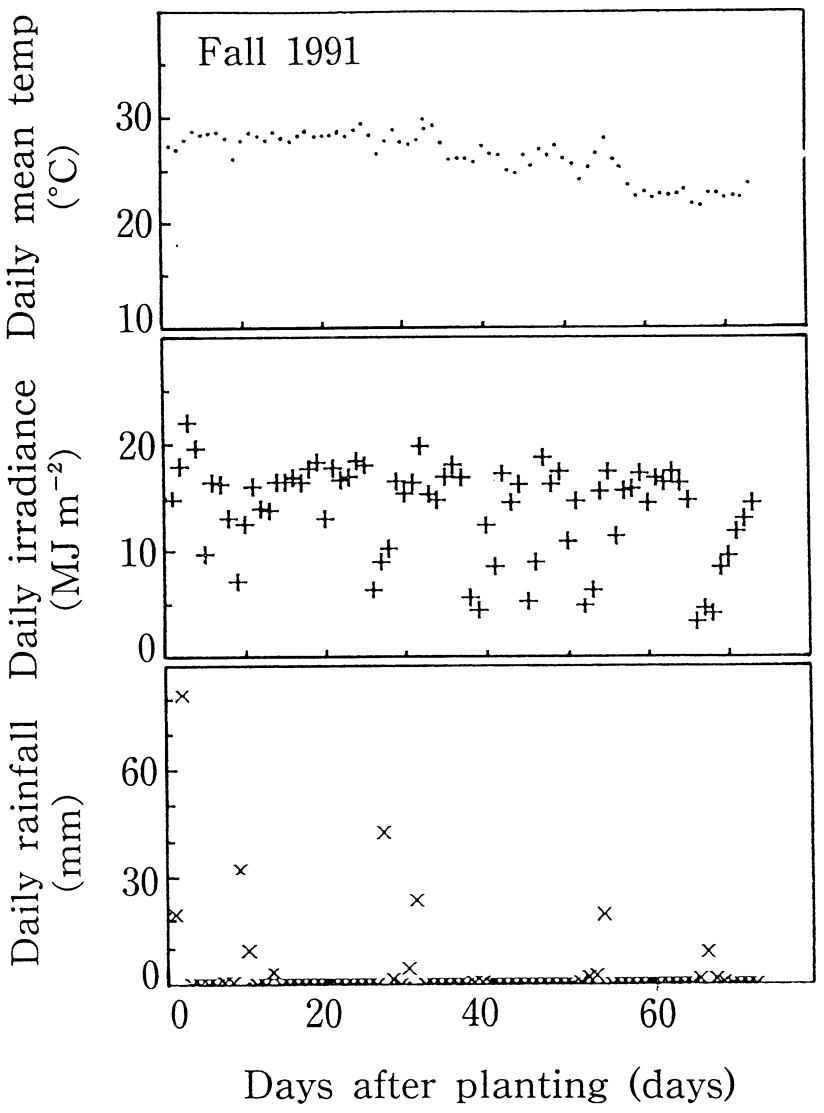

Fig. 1. The daily mean temperature, irradiance and rainfall during the growing season of fall 1991.

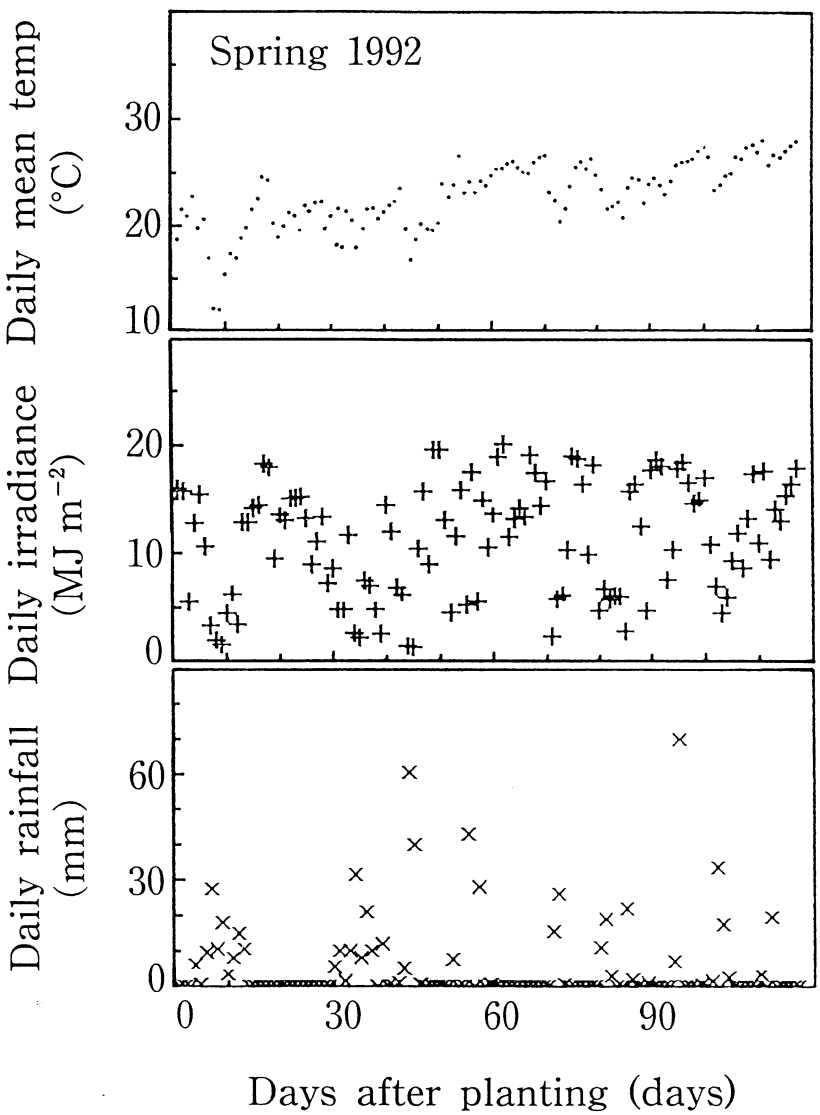

Fig. 2. The daily mean temperature, irradiance and rainfall during the growing season of spring 1992.

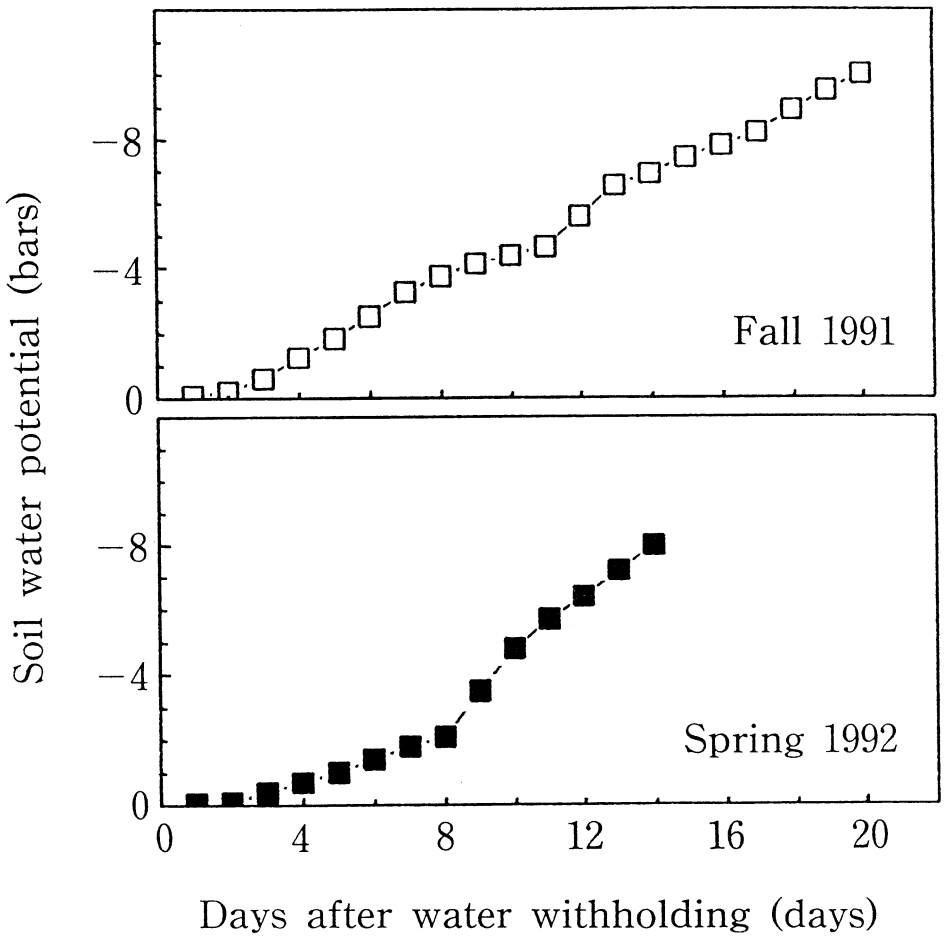

Fig. 3. Changes of soil water potential after water withholding during the treatment periods in fall crop 1991 and spring crop 1992, respectively.

Plant growth in response to different levels of soil water deficit was investigated by measuring growth parameters after stress period, ca. one week after the 50% of silking for the fall season of 1991 and at the 50% of silking for the spring season of 1992. It appeared that plant height was not significantly affected to desiccation during reproductive phase, as vegetative growth was ended, in fall crop, but was reduced at −8.0 bars when stress occurred in the vegetative phase of spring crop (Table 1). Chotena *et al.* (1980) and Classen and Shaw (1970) noted that plant height of maize can be reduced by drought stress. Number of leaves per plant was unchanged by soil water deficits, whereas leaf area was decreased by −5.0 and −8.0 bars of water potential in 1991 and 1992, respectively (Table 1). When soil water potential lowered to −5.0 bars in fall, but not in spring, plant weight declined (Table 2). Leaf and stem dry weights were reduced 16% by water stress when soil water potential reached down to −5.0 and −10.0 bars, respectively. Obviously leaf growth was more sensitive to desiccation than stem growth. Miller and Duley (1925) and Acevedo *et al.* (1971)

also found that leaf growth responds more readily to water stress than other parts of maize plant. Van Volkenburgh and Boyer (1985) showed that proton excretion in wall-loosening events for cell enlargement is inhibited and hence reduces leaf growth rate upon water deficit. Further, a close relationship between leaf growth and soil water potential in maize was concluded by Boyer (1970a) and Michelena and Boyer (1982) in longer term experiments.

Based on the heading and silking dates (Table 3), maize reproductive development did not dramatically influenced by water stress within the test ranges (Table 3). Apparently dry matter accumulation during the growing season control plant development rather than during the drought period. Whereas, Frederick *et al.* (1989) and others (Herrero and Johnson, 1981; Kiesselbach, 1950; Salter and Goode, 1967) reported that the silking and anthesis dates were delayed and grain-filling period was decreased by drought stress in maize when stress initiated from the V7 (Richie *et al.*, 1986) to the R 2 stage.

Table 1. Influence of soil water deficits on growth characters of maize Tainung No. 1 in fall crop of 1991 and spring crop of 1992.

Moisture stress treatment	Plant height	Leaf number	Leaf area
	----------cm----------	No. plant^{-1}	cm^2 plant^{-1}
Fall 1991*			
Control	225.9	12.3	4,696
− 2.5 bars	219.5	11.6	4,357
− 5.0 bars	216.4	11.7	4,148
−10.0 bars	212.1	11.0	3,839
$LSD_{(0.05)}$	14.7	1.3	408
Spring 1992**			
Control	210.3	10.2	3,393
−2.5 bars	212.2	10.1	3,275
−5.0 bars	208.0	10.0	2,981
−8.0 bars	195.5	9.3	2,477
$LSD_{(0.05)}$	12.9	0.9	485

* Water stress was imposed in reproductive growth phase (September 10 to September 29, 1991) and measurements were taken on 30 September 1991 (one week after the 50% silking).

**Water stress was imposed in vegetative growth phase (April 25 to May 7, 1992) and measurements were taken on 22 May 1992 (the 50% silking).

Table 2. Influence of soil water deficits on plant dry weights (80 °C for 72 h) of maize Tainung No. 1 in fall crop of 1991 and spring crop of 1992.

Moisture stress treatment	Leaf	Stem	Root	Sum
	g plant^{-1}			
Fall 1991*				
Control	29.48	51.11	18.98	99.57
− 2.5 bars	26.68	47.27	19.73	93.68
− 5.0 bars	24.84	46.82	18.35	90.00
−10.0 bars	22.12	42.79	18.08	83.00
$LSD_{(0.05)}$	3.55	5.01	1.47	7.79
Spring 1992**				
Control	19.46	35.78	17.34	72.58
−2.5 bars	20.28	35.75	17.26	71.77
−5.0 bars	19.55	34.97	15.64	70.15
−8.0 bars	17.31	31.76	14.81	63.87
$LSD_{(0.05)}$	3.93	5.25	3.26	9.97

* Water stress was imposed in reproductive growth phase (September 10 to September 29, 1991) and measurements were taken on 30 September 1991 (one week after the 50% silking).

**Water stress was imposed in vegetative growth phase (April 25 to May 7, 1992) and measurements were taken on 22 May 1992 (the 50% silking).

Table 3. Influence of soil water deficits on the heading and the silking dates of maize Tainung No. 1 in fall crop of 1991 and spring crop of 1992.

Moisture stress treatment	Heading date	50% Heading date	silking date	50% silking date
Fall 1991*				
Control	Sept. 17	Sept. 20	Sept. 19	Sept. 23
− 2.5 bars	Sept. 17	Sept. 21	Sept. 19	Sept. 23
− 5.0 bars	Sept. 17	Sept. 21	Sept. 19	Sept. 23
−10.0 bars	Sept. 17	Sept. 21	Sept. 20	Sept. 25
Spring 1992**				
Control	May 16	May 20	May 18	May 22
−2.5 bars	May 16	May 20	May 18	May 22
−5.0 bars	May 15	May 19	May 18	May 22
−8.0 bars	May 15	May 19	May 18	May 23

* Water stress was imposed in reproductive growth phase (September 10 to September 29, 1991).

**Water stress was imposed in vegetative growth phase (April 25 to May 7, 1992).

Influence of soil water deficits on some yield components of maize measured at harvest were listed in Table 4. It was shown that ear and kernel weights per plant were decreased with decreasing soil water potentials in both crop seasons. Kernel yield was ultimately reduced to 60% of the control at −10 bars in the fall season and to 80% of the control at −8 bars in the spring season (Table 5). Denmead and Shaw (1960) and Lorens *et al.* (1987) showed that soil water deficit during vegetative development of maize decreases vegetative growth, impairs the development of reproductive structures, and may lower kernel yield ultimately. As decreases in net photosynthetic rate associated with decreases in water potential (Boyer, 1970b; Beadle *et al.* 1973; Moss *et al.*, 1961), less photosynthate may be partitioned to vegetative tissues and lower soluble carbohydrate reserves may be retranslocated for reproductive development. Thus, the kernel capacity is smaller and consequently, yield is reduced (Simmons and Jones, 1985; Westgate and Boyer, 1985).

Table 4. Influence of soil water deficits on some yield components of maize Tainung No. 1 measured at harvest in fall crop of 1991 and spring crop of 1992.

Season stress treatment	Ear length	Ear number	Ear dry weight	Kernel dry weight	EPP***
	cm	No. plant^{-1}	g plant^{-1}	g plant^{-1}	%
Fall 1991*					
Control	18.1	1.5	165.97	137.12	86.8
− 2.5 bars	18.1	1.5	142.97	118.24	86.8
− 5.0 bars	17.6	1.4	127.82	105.56	83.1
−10.0 bars	17.4	1.3	106.97	87.45	82.4
$LSD_{(0.05)}$	0.8	0.3	11.09	8.26	5.8
Spring 1992**					
Control	18.2	1.2	166.92	140.38	83.1
−2.5 bars	17.8	1.3	153.66	129.17	79.4
−5.0 bars	18.1	1.3	152.54	127.46	77.7
−8.0 bars	17.5	1.3	141.20	115.81	78.4
$LSD_{(0.05)}$	1.1	0.4	11.57	6.55	6.3

* Water stress was imposed in reproductive growth phase (September 10 to September 29, 1991) and measurements were taken on 21 October 1991.

** Water stress was imposed in vegetative growth phase (April 25 to May 7, 1992) and measurements were taken on 23 June 1992.

***EPP: effective plant percentage.

Table 5. Influence of soil water deficits on yield of maize Tainung No. 1 in fall crop of 1991 and spring crop of 1992.

Moisture stress treatment	Ear dry weight	Kernel yield	Index
	kg ha^{-1}	kg ha^{-1}	%
Fall 1991			
Control	8,240	6,800	100
− 2.5 bars	7,100	5,870	86
− 5.0 bars	6,070	5,010	73
−10.0 bars	5,030	4,110	60
$LSD_{(0.05)}$	800	610	
Spring 1992			
Control	7,740	6,510	100
−2.5 bars	6,970	5,860	90
−5.0 bars	6,760	5,650	87
−8.0 bars	6,200	5,190	80
$LSD_{(0.05)}$	440	490	

* Water stress was imposed in reproductive growth phase (September 10 to September 29, 1991) and measurements were taken on 21 October 1991.

**Water stress was imposed in vegetative growth phase (April 25 to May 7, 1992) and measurements were taken on 23 June 1992.

Kernel yield has also been reported to be sensitive to water deficit during the reproductive growth (Denmead and Shaw, 1960; Grant *et al.*, 1989; Harder *et al.*, 1982; Ouattar *et al.*, 1987b; Westgate and Grant, 1989). In a controlled environment study, McPherson and Boyer (1977) stated that kernel yield of maize exposed to −18 to−20 bars of leaf water potential during kernel-filling period was 47 to 69% of the control yield. Kernel fill of maize can be reduced by drought stress due to decreases in carbon exchange rates (photosynthesis) and /or the duration of kernel fill (Chotena *et al.*, 1980; Classen and Shaw, 1970; Jones and Simmons, 1983; Jurgens *et al.*, 1978; McPherson and Boyer, 1977). Herrero and Johnson (1981) found that moisture stress during anthesis has a greater effect on floral development. Westgate and Boyer (1985) indicated that water deficit occurred at early reproductive phase limited the supply of photosynthate directly from concurrent photosynthesis for the subsequent kernel filling. Ouattar *et al.* (1987a) pointed out that source limitation (decrease of photosynthesis) was the cause of lower kernel weight. In addition, nutrition, nutrient diffusion rate from the soil matrix to roots (Barber, 1962; Olsen *et al.* 1965; Viets, 1972) and nutrient uptake by plants (O′ Toole and Baldia, 1982; Verasan and Phillips, 1978; Yambao and O′Toole, 1984) are decreased under soil moisture stress conditions. Such viewpoints support the results of this study.

The linear regressions of kernel yield and growth parameters in maize upon water stress in fall and spring crops were listed in Table 6. It suggested that leaf area, leaf weight and plant weight were three effective parameters in estimating maize production upon soil water deficits occurring in reproductive growth phase. Soil water potential, however, was the only element be employed on predicting maize production by water stress in both growth phases (Fig. 4) and kernel yield reductions depended on severity of soil moisture deficiency.

Table 6. The linear regressions of kernel yieid (Y) and growth parameters (X) in maize upon water deficits in fall crop of 1991 and spring crop of 1992.

Growth parameter	Season	Equation
Plant weight (cm)	Fall	Y=165.2827X−9,686.1950 r=.9944** (p=0.01)
	Spring	Y=121.1160X−2,626.2660 r=.8715 (p=0.13)
Leaf area (cm² plant-1)	Fall	Y=3.1923X−8,151.8110 r=.9974** (p=0.003)
	Spring	Y=1.2342X+2,060.9690 r=.9188 (p=0.08)
Leaf weight (g plant-1)	Fall	Y=371.4876X−4,129.4520 r=.9979** (p=0.002)
	Spring	Y=274.5262X+545.3225 r=.6410 (p=0.36)

r : correlation coefficient.

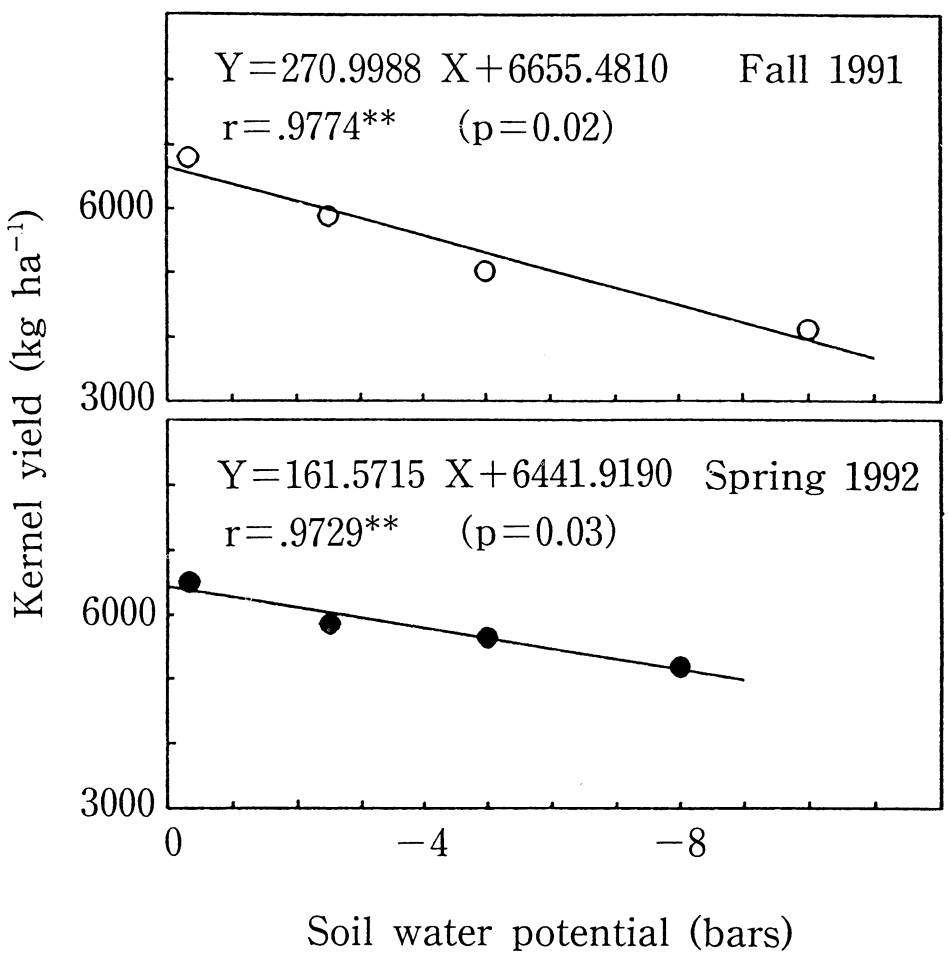

Fig. 4. The linear regression of kernal yield and soil water potential in maize in fall crop of 1991 and spring crop of 1992.

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玉米 (Zea mays L.) 生長與產量對土壤缺水之反應

(二)缺水時期及缺水程度之影響

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摘 要

水分爲本省玉米生產之一項主要限制因子，因此殊有必要詳加探討各局地環境下玉米生長與產量和土壤水分之關係。本文研究係以玉米單交品種臺農一號爲材料，在臺灣省農業試驗所農場進行田間試驗，評估玉米缺水時期及土壤缺水程度對玉米生產之影響。土壤缺水採人工斷水達成，即在自然狀況下實施停止灌水方式達到預先設定之土壤水分含量，土壤水分潛勢範圍介於－1/3（對照組）至－10 bars 之間。1991年秋作完成生殖生長期缺水處理，而在1992年則完成營養生長期缺水處理。根據試驗結果，玉米每株葉片數不因土壤缺水改變，而當土壤水分潛勢下降至－5 bars（秋作）及－8 bars（春作）時，葉面積明顯減少。營養生長時期13天斷水至－8 bars 時，影響玉米植株高度（於50%雌穗吐絲期測量），惟並未顯著延長或縮短雄穗開花及雌穗吐絲日期。生殖生長時期斷水達－5 bars 時，將造成植株乾重減少10%以上。每公頃穗重及籽粒產量在兩期作均因土壤缺水而降低，秋作在－10 bars、春作在－8 bars 下，籽粒產量分別僅及對照區者之60及80%。本文結果亦發現，在試驗之缺水範圍內，土壤水分潛勢與玉米籽粒產量間呈現顯著直線相關，產量隨土壤水分潛勢下降而降低。

關鍵詞：生長、產量、玉米、土壤缺水、缺水時期、缺水程度。

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2. 臺灣省農業試驗所副研究員、研究員及助理研究員。臺灣省 臺中縣 霧峰鄉。